Top Mass Measurements by the CMS Collaboration

Steve Wimpenny
Dept. of Physics & Astronomy
UC Riverside

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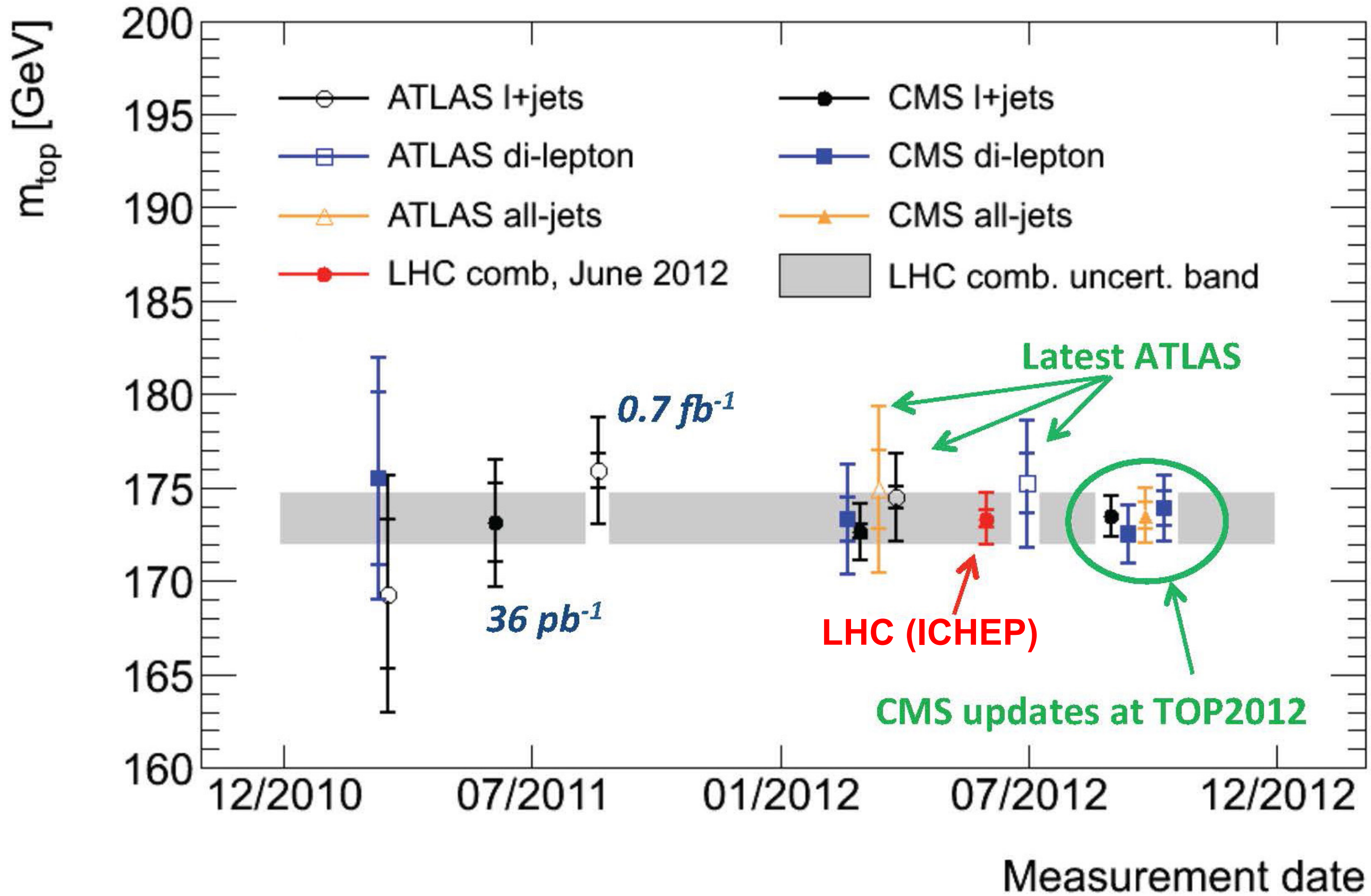
★ Topics Covered

- *Standard Collider m_t measurents of m_t :*
  - *Completed 7 TeV analyses*
  - *Preliminary CMS combined result*
  - *Measurement of top-antitop mass difference*
  - *Kinematic studies*

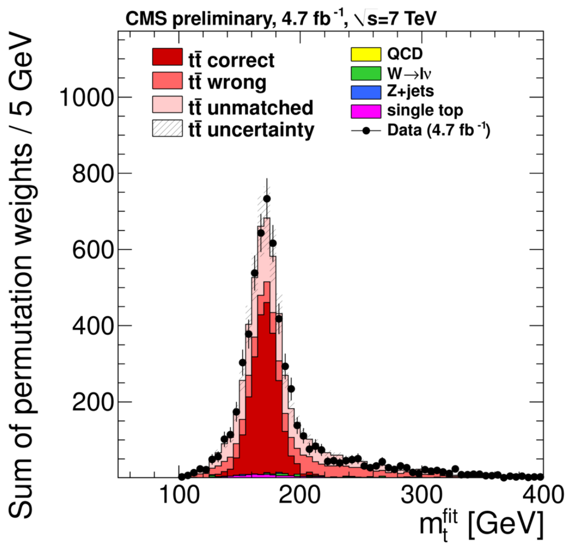
- *Alternative measurement methods:*
  - *Kinematic endpoint analysis*
  - *m_t from measured cross section*
    α_s from measured cross section

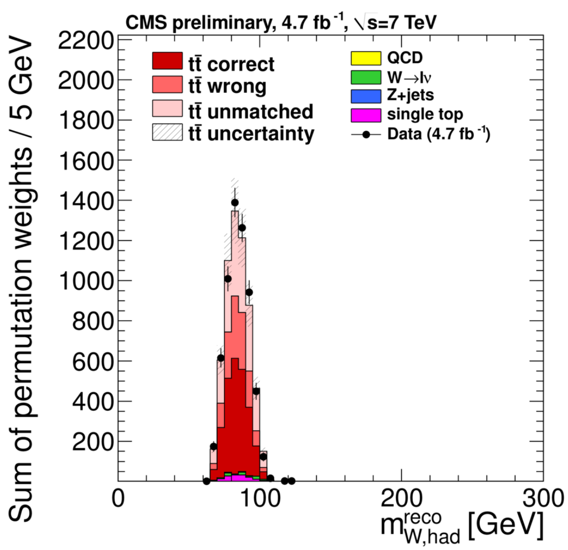
- *LHC Combinations:*
  - *Summer 2012*
  - *Ongoing studies*

Evolution of CMS Mass Measurements at 7 TeV

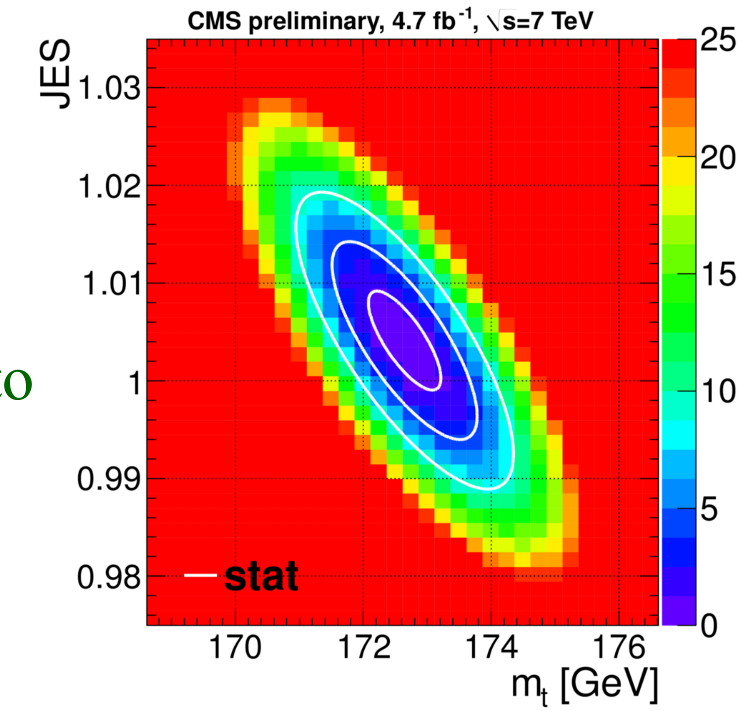


i.) Lepton (e,μ) + Jets Channel (JHEP 12 (2012) 105)





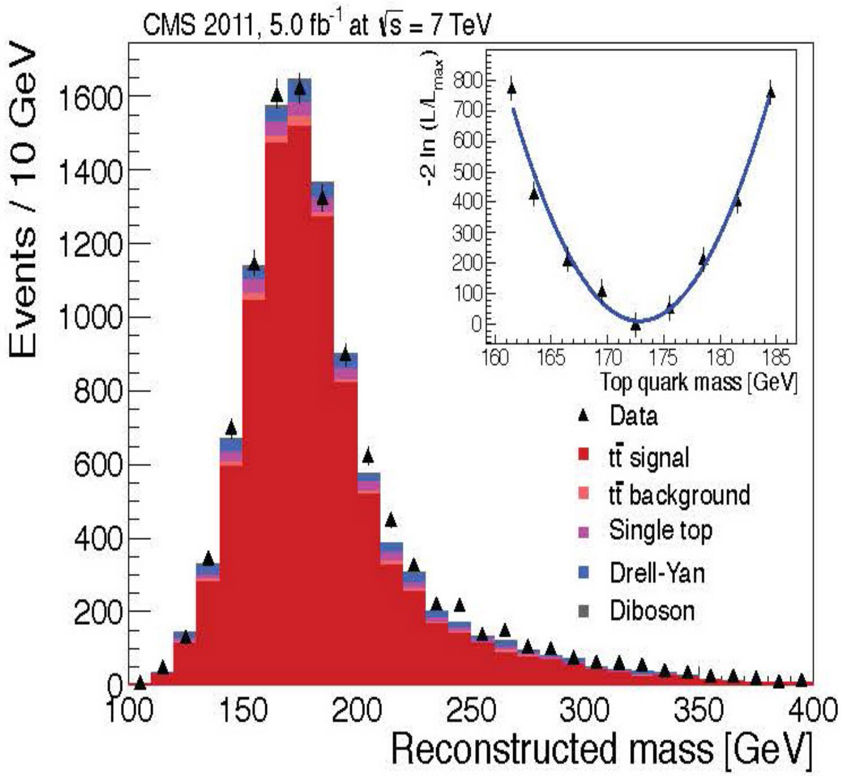
5174 events
Simultaneous fit to JES and m_t



m_t = 173.49 ± 0.43 (stat.+JES) ± 0.98 (syst.) GeV

Most precise CMS measurement

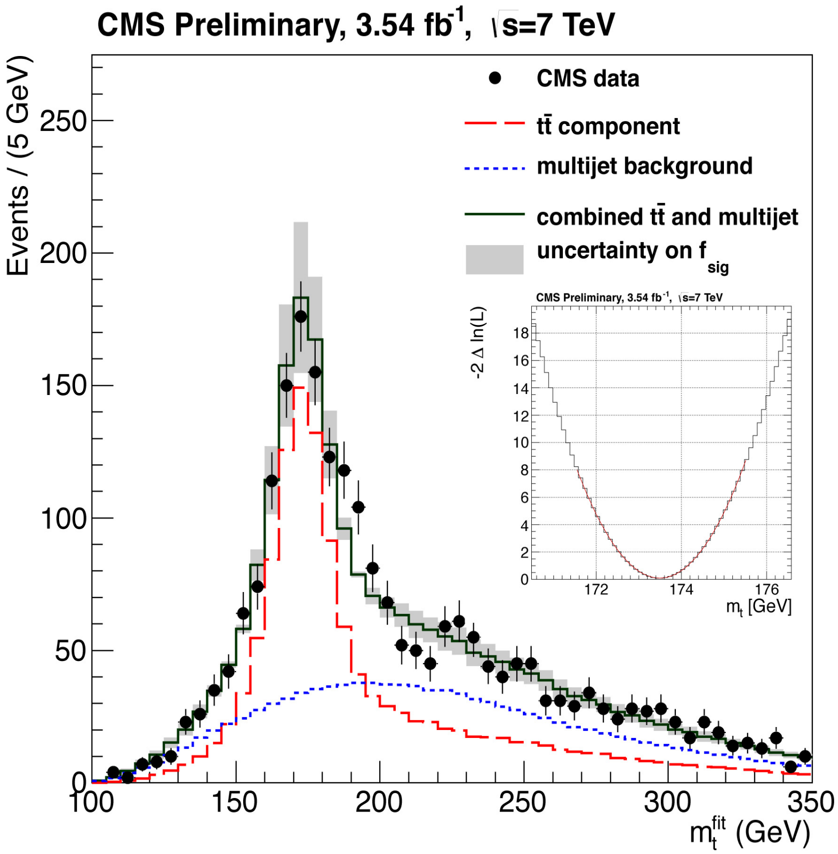
ii.) Dilepton (ee, μμ, eμ) + Jets Channel (EPJC 72 (2012) 2202)



2418 events
Analytical Matrix Weighting Technique (AMWT)
with JES = 1

m_t = 172.50 ± 0.43 (stat.) ± 1.48 (syst.) GeV

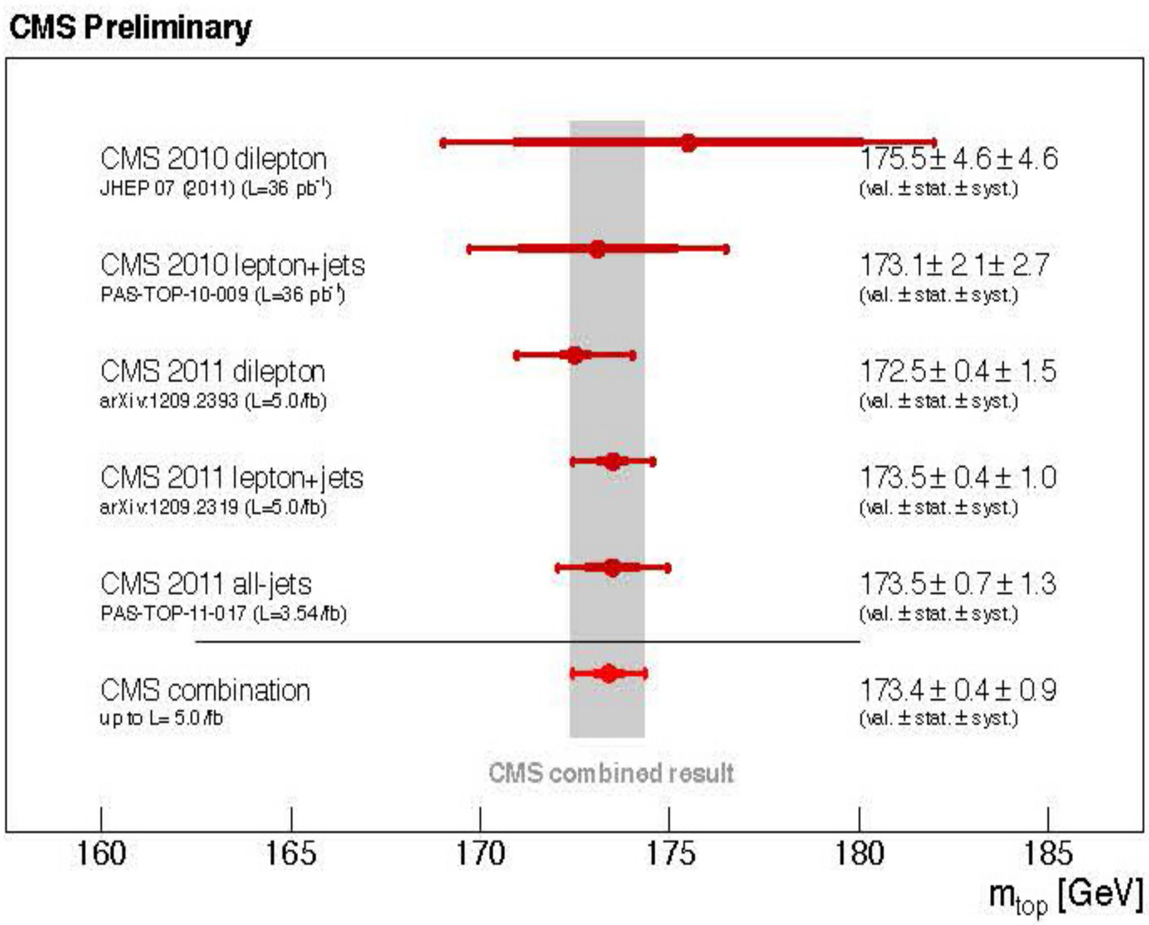
iii.) All-hadronic Channel (CMS-PAS-TOP-11-017)



2418 events
Constrained kinematic fit
with JES = 1

m_t = 174.49 ± 0.69 (stat.) ± 1.25 (syst.) GeV

Preliminary Combined CMS Measurement (CMS-PAS-TOP-11-018)



all channels
have
similar precision
(< 1%)
and are
systematics
limited

$m_t = 173.36 \pm 0.38$ (stat.) ± 0.91 (syst.) GeV (0.6 % Precision)

	Dileptons 2010	Lepton+jets 2010	Dileptons 2011	Lepton+jets 2011	All jets 2011	Correlation between channels	Correlation between years	Combination
Measured m_t	175.50	173.10	172.50	173.49	173.49			173.36
Statistical Uncertainty	4.60	2.10	0.43	0.27	0.69	0	0	0.38
iJES: *in-situ* JES factor	n/a	n/a	n/a	0.33	n/a	0	0	0.24
bJES: relative b-jet scale	0.90	0.90	0.71	0.61	0.49	1	1	0.55
dJES: η and p_T-dependent JES	2.10	2.10	0.94	0.28	0.97	1	1	0.32
rJES: other uncorrelated JES	3.30	n/a	n/a	n/a	n/a	0	0	0.07
Lepton energy scale	0.30	n/a	0.14	0.02	n/a	1	1	0.03
MC generator	0.50	n/a	0.04	n/a	n/a			0.01
ISR/FSR	0.20	0.20	n/a	n/a	n/a			0.03
PDF	0.50	0.10	0.09	0.07	0.06			0.06
Factorization scale	0.60	1.10	0.55	0.24	0.22			0.17
ME-PS matching threshold	0.70	0.40	0.19	0.18	0.24			0.16
Signal						1	1	
Jet energy resolution	0.50	0.10	0.14	0.23	0.15			0.20
b-tagging	0.40	0.10	0.09	0.12	0.06			0.10
E_T^{miss} scale	0.10	0.40	0.12	0.06	n/a			0.01
Detector Modeling						1	1	
Underlying event	1.30	0.20	0.05	0.15	0.32	1	1	0.15
Background MC	0.10	0.20	0.05	0.13	n/a	1	1	0.07
Background Data	n/a	0.40	n/a	n/a	0.20	0	0	0.07
Fit calibration and MC statistics	0.20	0.10	0.40	0.06	0.13	0	0	0.08
Pile-up	1.00	0.10	0.11	0.07	0.06	1	0	0.09
Color reconnection	n/e	n/e	0.13	0.54	0.15	1	1	0.45
Trigger	n/a	n/a	n/a	n/a	0.24	1	1	0.07
Total Systematic Uncertainty	4.52	2.63	1.41	1.03	1.25			0.91
Total Uncertainty	6.45	3.37	1.46	1.07	1.43			0.99
Combination weight	-0.023	-0.109	0.124	0.733	0.275			

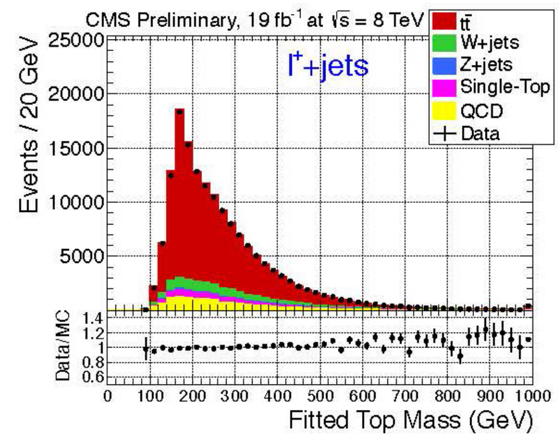
Dominant systematic: uncertainties

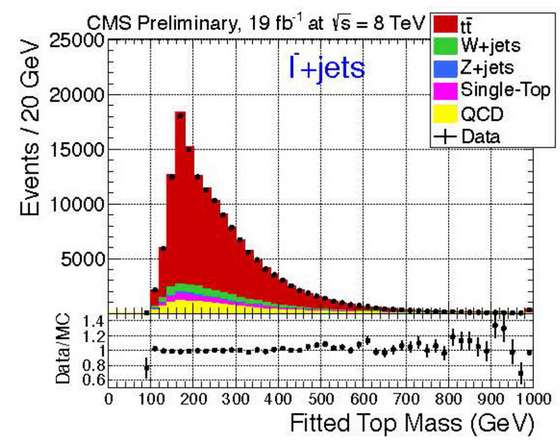
Jet Energy Scale, Color Reconnection
Factorization Scale and ME-PS Matching

Top and Anti-top Mass Difference (CMS-PAS-TOP-12-031)

1st CMS m_t measurement using 8 TeV data: Test of CPT invariance in top system

Source	Estimated effect (MeV)
Jet energy scale	**17** ± 15
Jet energy resolution	8 ± **11**
b vs. $\bar{b}$ jet response	**64** ± 7
Signal fraction	**45** ± 2
Background charge asymmetry	**12.43** ± 0.03
Background composition	**50** ± 1
Pileup	**17.4** ± 0.4
b-tagging efficiency	**20** ± 8
b vs. $\bar{b}$ tagging efficiency	**43** ± 6
Method calibration	15 ± **54**
Parton distribution functions	**12** ± 3
Total	122





Δm_t = - 272 ± 196 (stat.) ± 122 (syst.) MeV

CMS 7 TeV measurement:

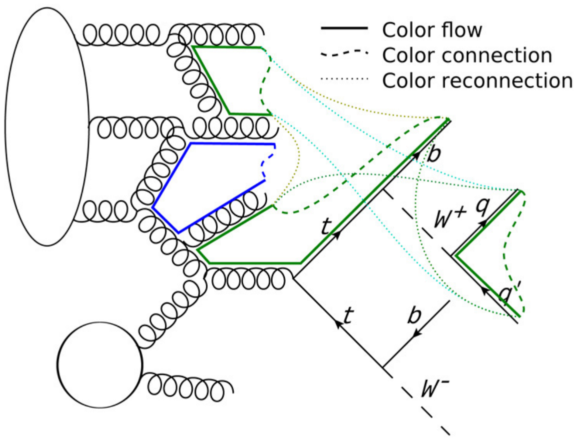
Δm_t = -0.44 ± 0.46 (stat.) ± 0.27 (syst.) GeV   JHEP 06 (2012) 109

Kinematic Studies (CMS-PAS-TOP-12-029)

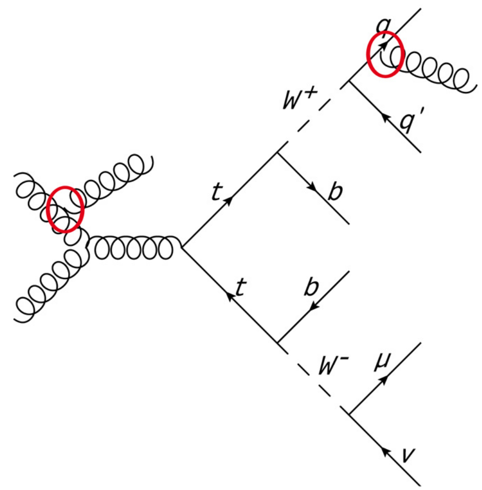
Search for possible bias due to systematic uncertainties - lepton + jets channel

e.g.

Color Reconnection



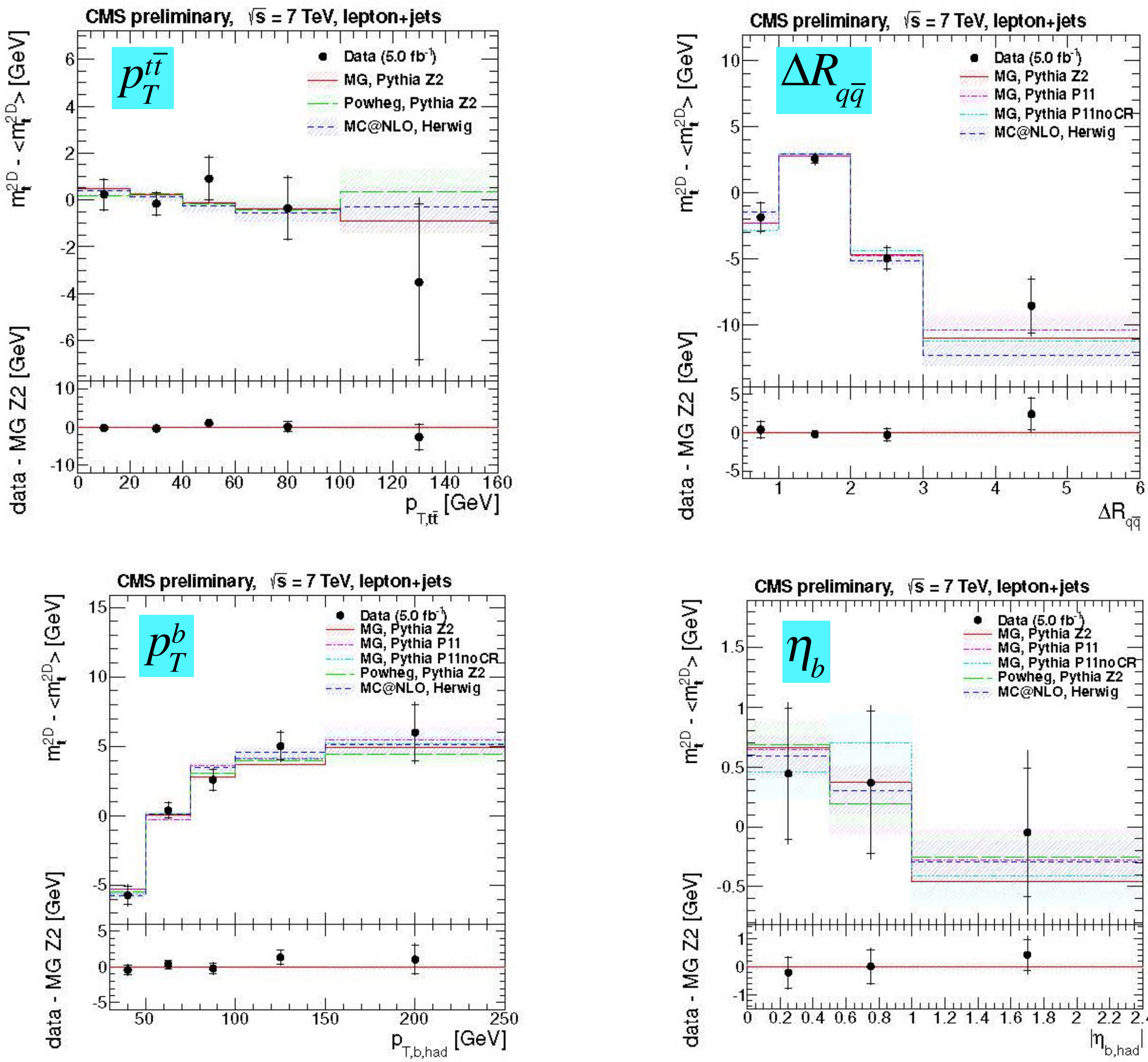
ISR and FSR



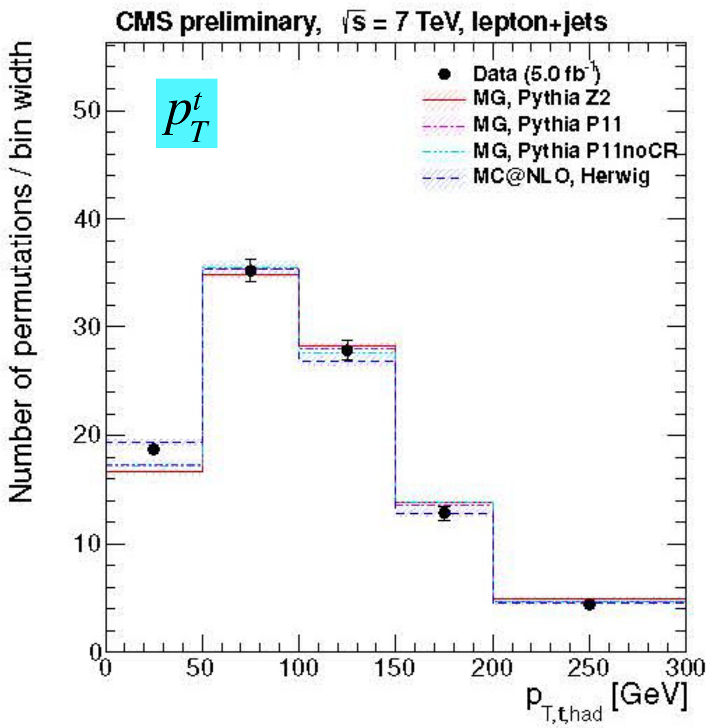
Measure top quark mass as a function of kinematics (12 variables) using the analysis method taken from TOP-11-015

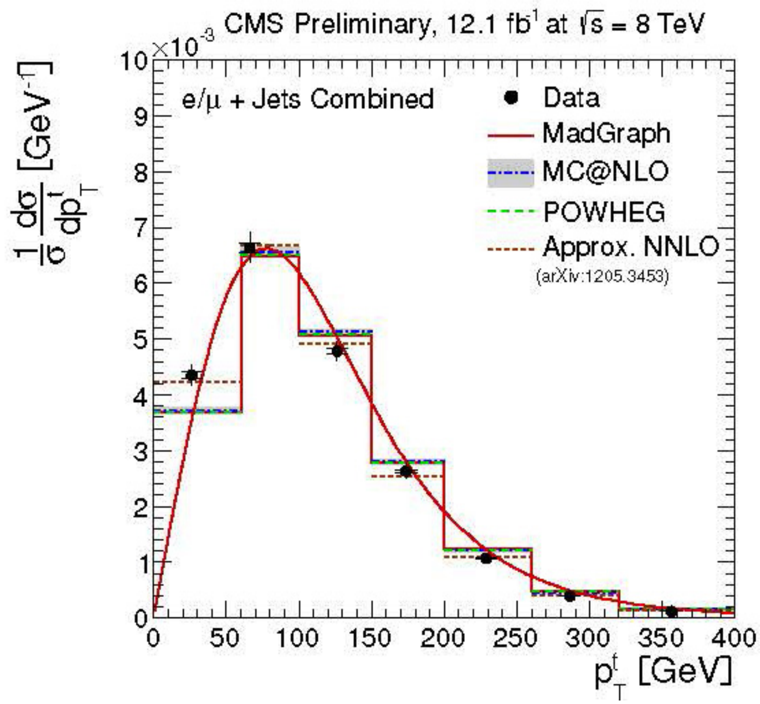
Compare results to:

Madgraph+Pythia Z2 tune (CMS default)
Madgraph+Pythia P11 and P11noCR
MC@NLO+Herwig6
POWHEG+Pythia Z2 tune



→ no evidence for kinematic bias and dramatic effects are excluded with current precision all MC models follow trends equally well

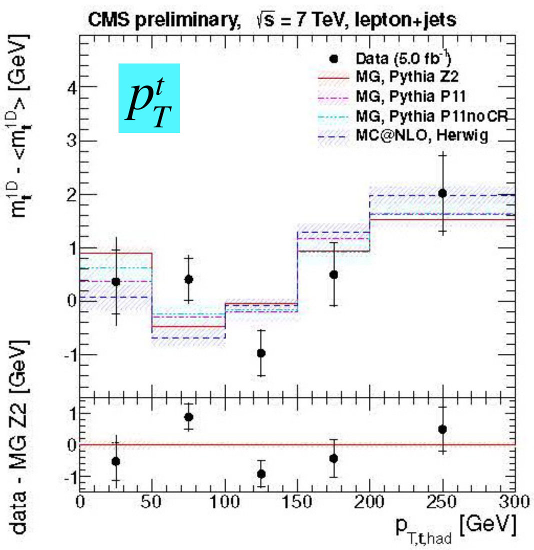




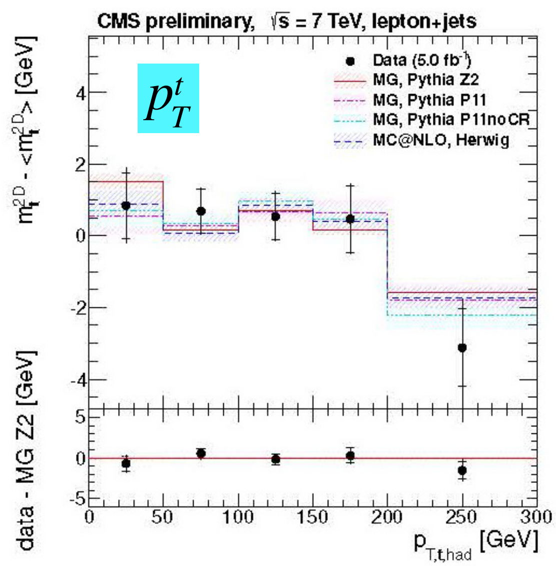
one exception – p_T^t

MC@NLO gives a better description of low p_T behavior

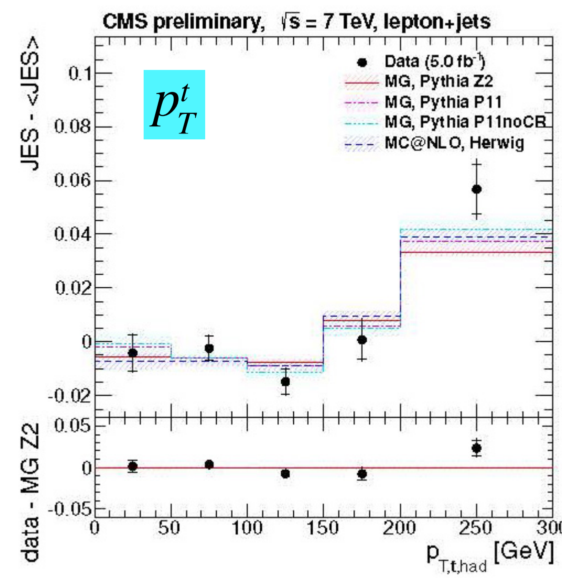
also seen in CMS differential cross section measurements (CMS-PAS-12-027) comparison of m_t (JES=1) and m_t and JES simultaneous fits provides additional information about how the fits operate



m_t (JES=1)



m_t



JES

$p_T \geq 200$ GeV ➔ onset of jet merging ➔ ISR/FSR jet included into mass calculation

m_t (JES=1) ➔ no significant effect

simultaneous m_t and JES fit ➔ complementary variations

both cases ➔ behavior modeled by simulations

	Fig.	Observable	m_t^{1D} χ^2	JES χ^2	m_t^{2D} χ^2	Ndf
CR	1	$\Delta R_{q\bar{q}}$	1.01	3.41	1.49	3
	2	$\Delta\phi_{q\bar{q}}$	2.31	2.18	2.89	3
	3	$p_{T,t,had}$	9.40	7.83	2.41	4
	4	$\|\eta_{t,had}\|$	0.41	3.33	3.17	3
ISR/FSR	5	H_T	3.18	1.19	2.24	4
	6	$m_{t\bar{t}}$	2.52	2.98	2.25	4
	7	$p_{T,t\bar{t}}$	3.39	1.67	2.18	4
	8	Jet multiplicity	1.47	2.00	1.56	2
b-quark kinematics, CR	9	$p_{T,b,had}$	0.81	2.35	2.17	4
	10	$\|\eta_{b,had}\|$	2.64	0.30	0.48	2
	11	$\Delta R_{b\bar{b}}$	4.87	2.61	8.01	3
	12	$\Delta\phi_{b\bar{b}}$	2.87	3.85	6.86	3

12 observables studied:

global agreement is quite good $\chi^2 = 68.6 / 78$ dof $\rightarrow$ Prob. = 77%

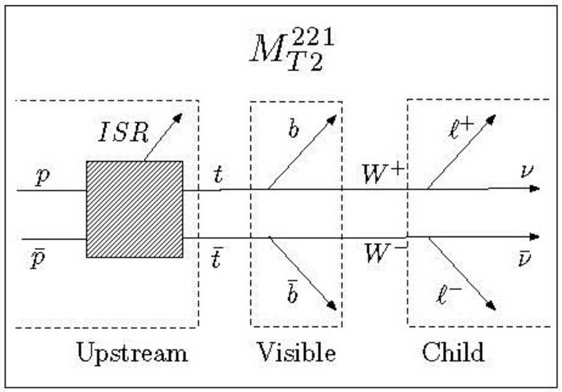
(m_t fit (1D) and JES fit vs Madraph + Pythia Z2 tune)

no evidence for large bias from CR, ISR/FSR, or b-quark kinematics

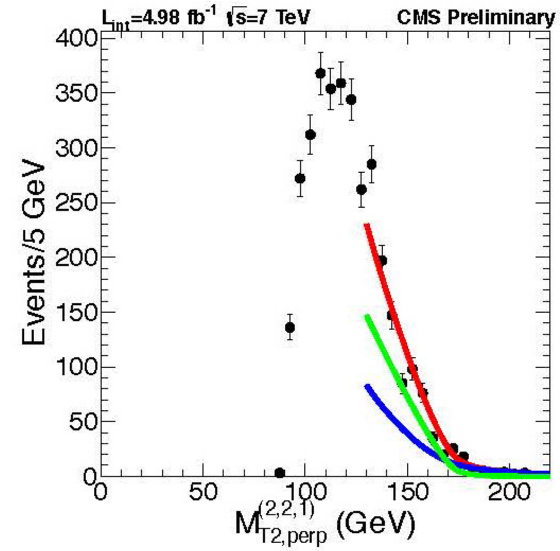
no evidence for large bias due to difference between m_t (MC) and m_t?

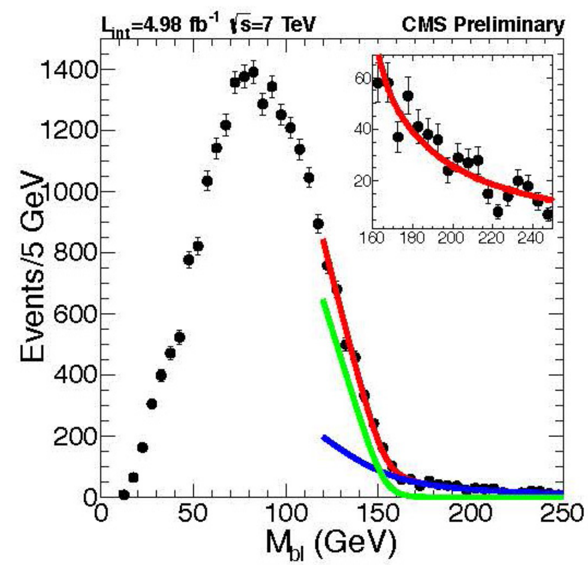
Kinematic Endpoint Analysis (CMS-PAS-TOP-11-027)

Perform a simultaneous fit to the endpoints of the observed mass spectra for M_{T2} and M_{bl} (variables chosen to be insensitive to ISR)



$M_T^{(2,2,1)} \Rightarrow t \rightarrow Wb$ decay

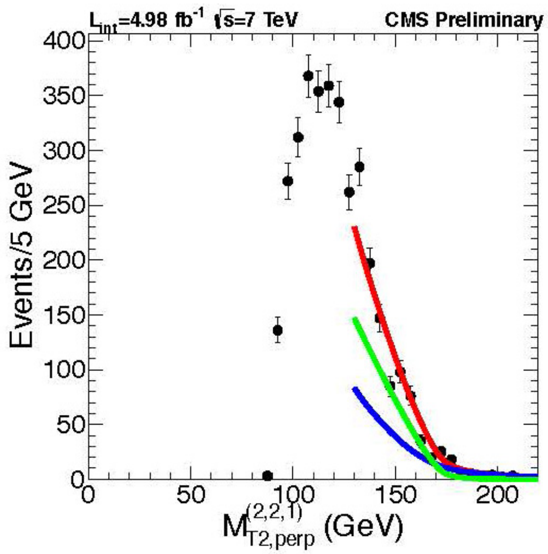


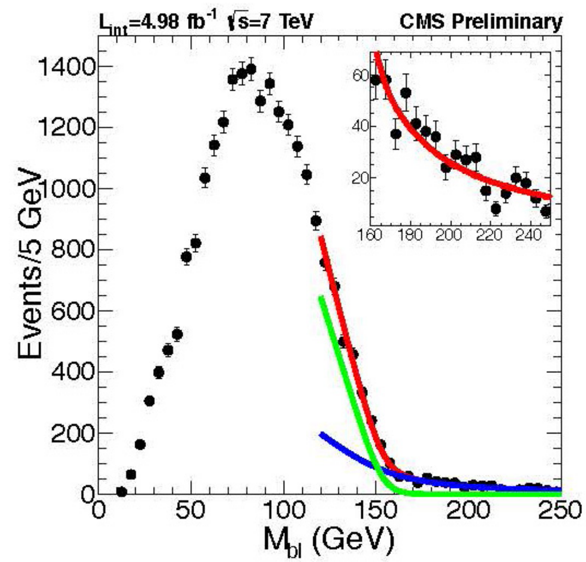


fit (red) = combination of Adaptive Kernal Estimator (blue - fitted to background data)

+

Linear Kink Function (green) convolved with event-by-event resolutions





CMS analytic implementation avoids use of MC calibration

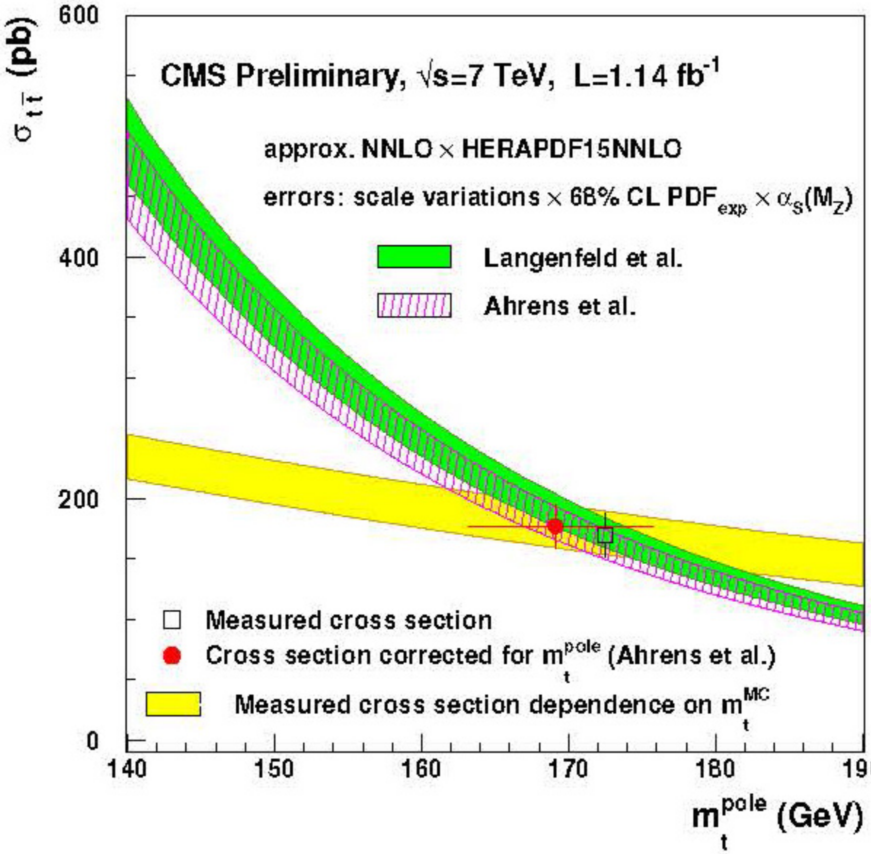
➔ systematics uncertainties partially uncorrelated with standard analyses

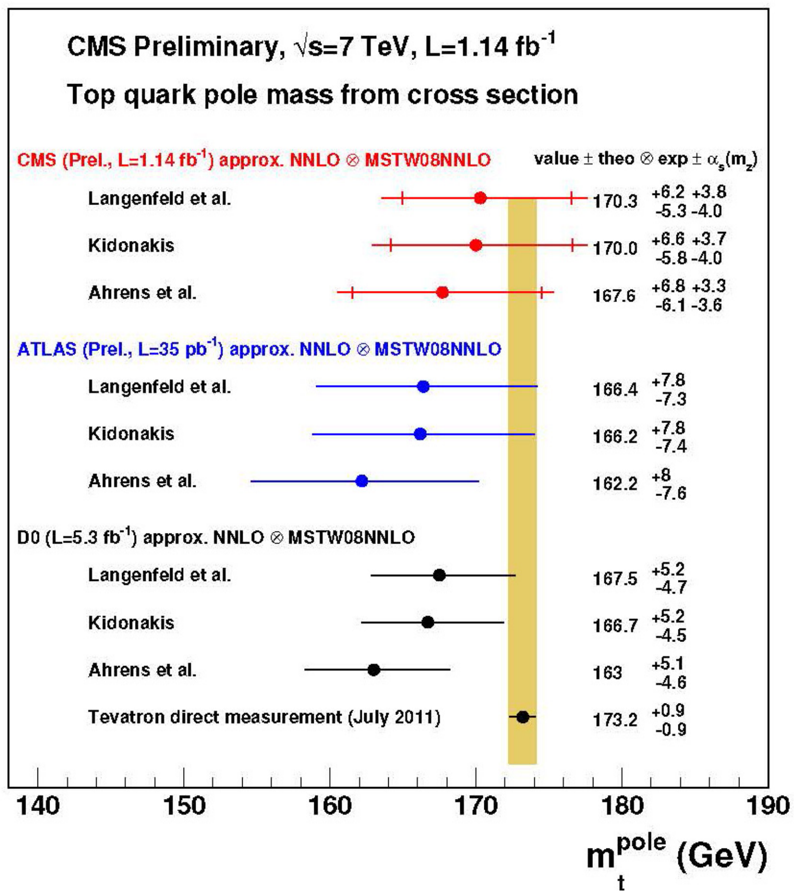
$$m_t = 173.9 \pm 0.9\ (\text{stat.})\ ^{+1.2}_{-1.8}\ (\text{syst.})\ \text{GeV}$$

Paper in preparation

Correlations with standard dilepton analysis under study
(preparation for inclusion in new CMS combination)

m_t from Production Cross Section (CMS-PAS-TOP-11-008)



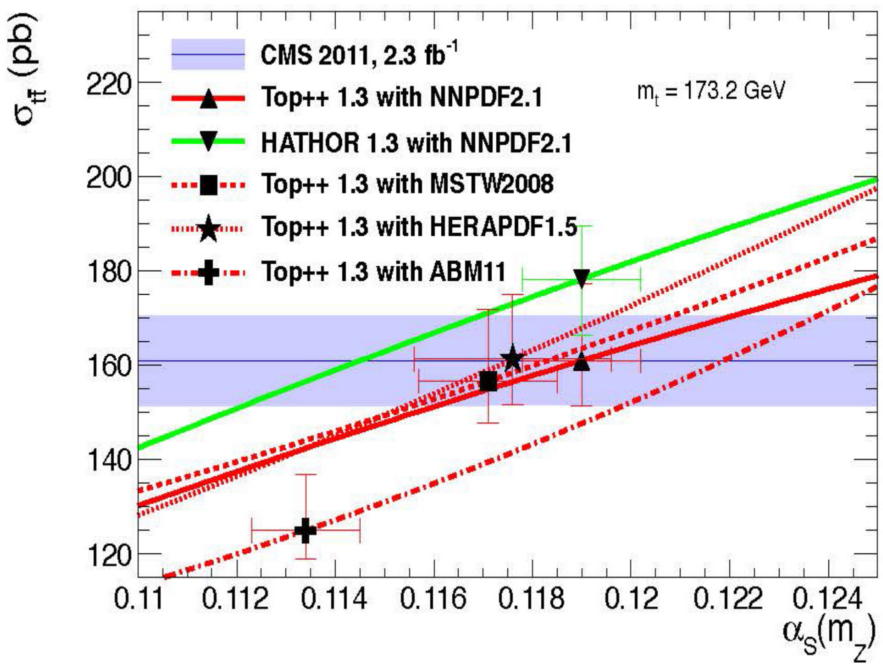


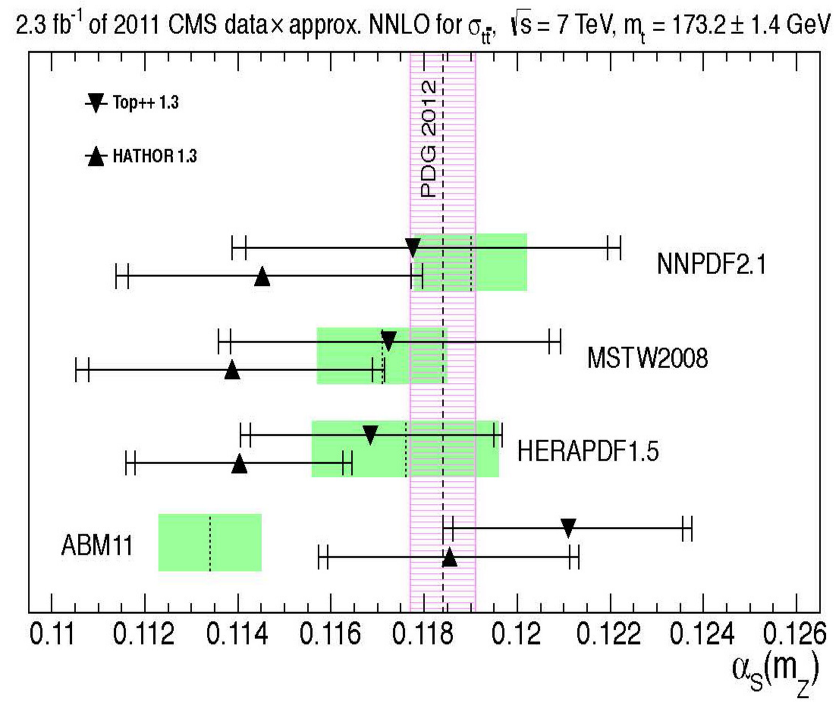
extract m_t from dilepton cross section measurement using theory

➔ mass is theoretically well defined but measurements are less precise (CMS: ~ 4%)

α_s from Production Cross Section (CMS-PAS-TOP-12-022)

can also extract α_s, taking measured m_t as an input …….

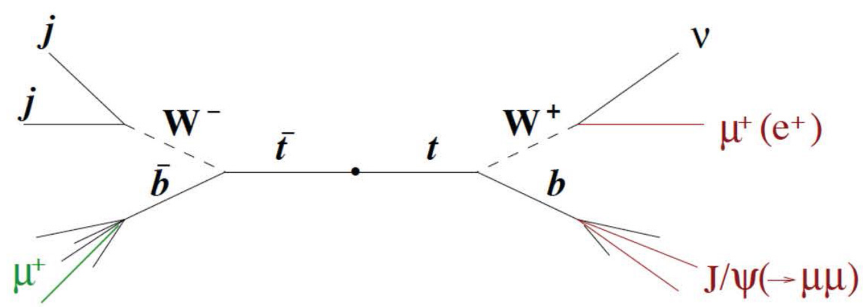




➔ 1st measurements of α_s using the top-antitop system

Paper with updated results for m_t and α_s using exact NNLO theory is in preparation
- anticipate improvement in mass precision by ~ factor of 2

m_t Using events with J/ψ to dilepton decays



Advantage:

Theoretically well defined with decreased sensitivity to b-jet JES

Difficulty:

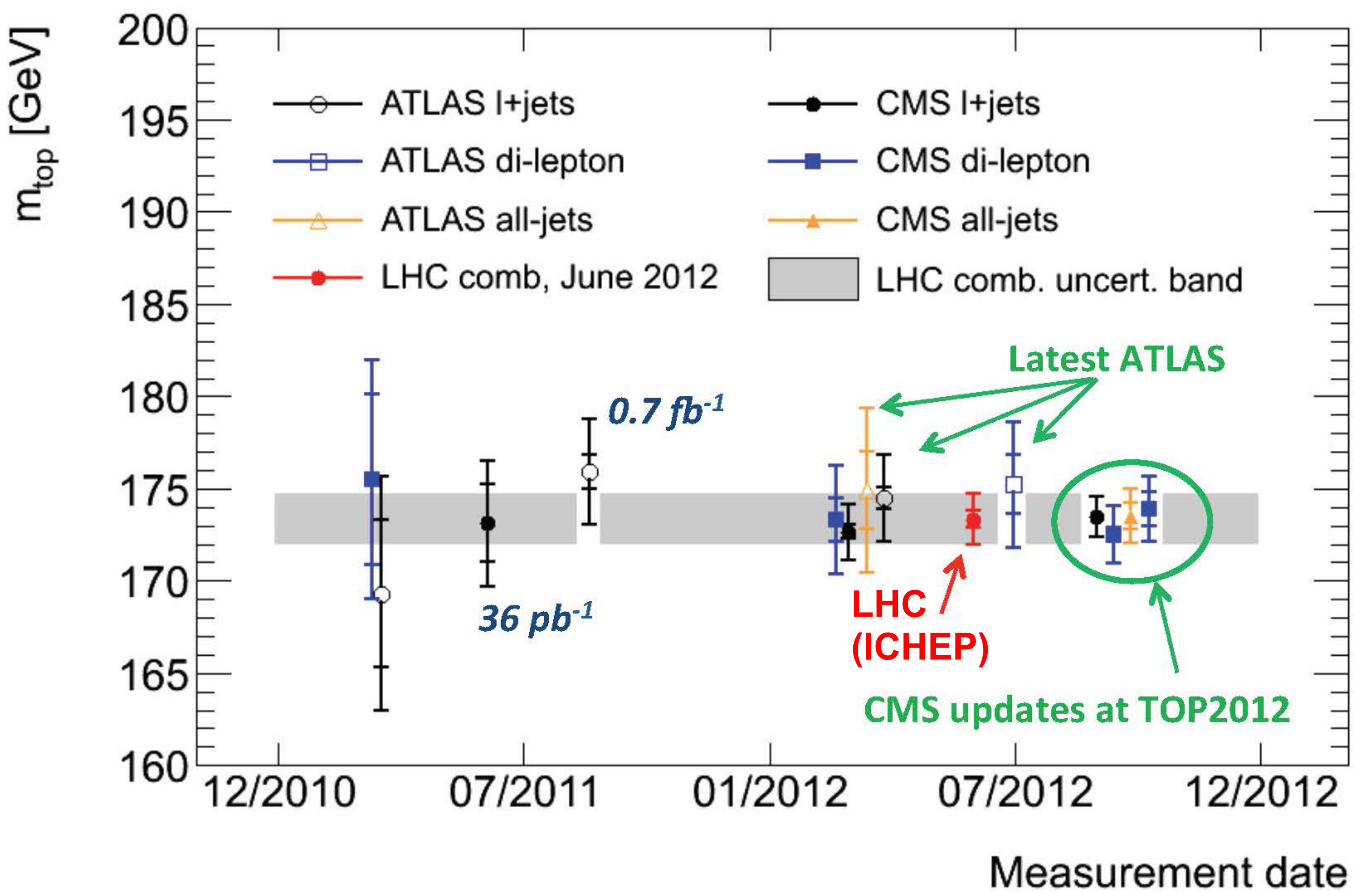
Statistical Precision

Initial studies:

- observe a J/ψ signal in di-muon decay channel using lepton+jets data
- estimated statistical sensitivity using 20 fb^{-1} of 8 TeV data
  (based on CMS and Tevatron studies) ~ 7 GeV

LHC Combination (CMS-PAS-TOP-12-001, ATLAS-CONF-2012-095)

The first LHC mass combination was produced last summer for ICHEP



$m_t = 173.3 \pm 0.5$ (stat.) ± 1.3 (syst.) GeV

Summer 2012 LHC m_t Combination ICHEP 2012

$m_t = 173.3 \pm 0.5$ (stat.) ± 1.3 (syst.) GeV (0.8 % Precision)

This is based on the published results from ATLAS and preliminary and published results from CMS

It does not include/use:

- the 2011 dilepton measurement from ATLAS
- the all-hadronic measurement from CMS
- the published lepton+jets & dilepton measurements from CMS

ATLAS and CMS are working towards a new combined result from the LHC for this summer's conferences

Studies for Future Combinations

Work in progress:

- improvements to the treatment of the error correlations between ATLAS and CMS

- investigation of the uncertainties due to b-quark D(z) modeling and its coverage in the current b-JES uncertainty

- study of the uncertainties due to the fragmentation modeling (cluster vs string….) and its coverage in the current b-JES/JES uncertainties

- study of the uncertainties due to the modeling on the finite top and W-decay widths

These are needed both for the next LHC combination and a future World (Tevatron+LHC) combination

Summary

Mass measurements from the LHC have reached a comparable precision to the combined Tevatron results.

The preliminary CMS combined result is

$$m_t = 173.36 \pm 0.38\ (\text{stat.}) \pm 0.91\ (\text{syst.})\ \text{GeV}$$

based on the data taken at 7 TeV (~20 % of Run 1 data)

Better precision is possible. Improved data and simulation statistics will help, as will require the inclusion of results using different analysis methods. Improvements to the modeling of the data and an improved understanding of its limitations will also play a role.